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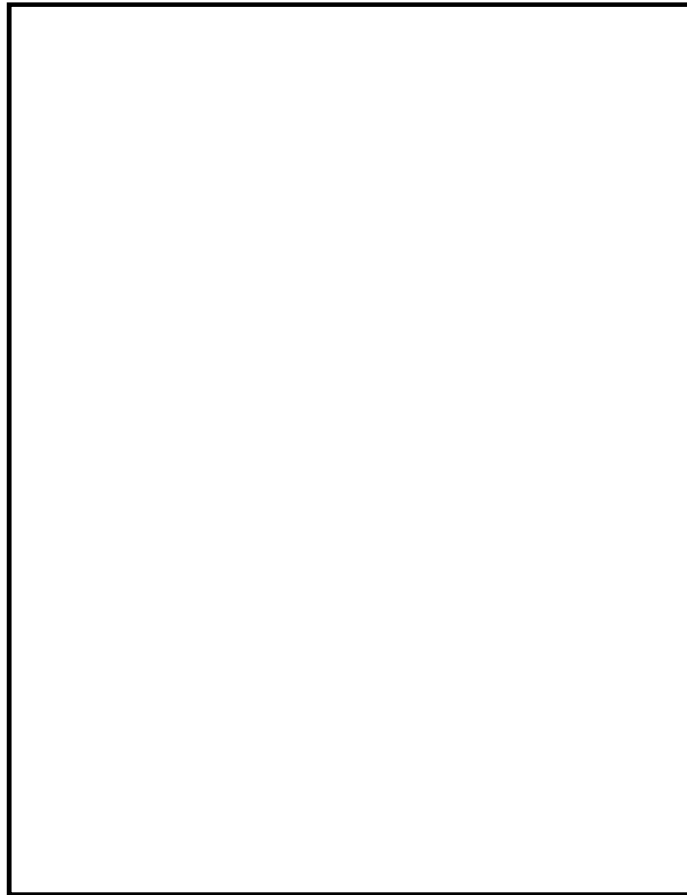
Paleolimnological Analysis of the History of Melioration
in the Great Salt Lake, Utah

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Final Report to the Utah Water Division
Salt Lake City

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Dr. Katrina Moser Preparing the Glew Corer to
Collect Sediment in the Great Salt Lake (Gunnison Bay)

Abstract

Three sediment cores from Lake Ute were analyzed to determine the magnitude of the deposition of 21 metal contaminants. In the main lake (Gilbert Bay), zinc, cadmium, silver, molybdenum, tin, mercury and arsenic concentrations began to increase in the 1800s or early 1900s and peaked in the 1950s. These increases were associated with mining and smelting activities for these metals in Utah. Co-60 fallout data indicate that concentrations of copper, lead and iron were above background levels in the 1950s. Since the 1950s, concentrations of most metals in the sediment have decreased, coincident with decreases in mining and improved smelting technologies. However, many metals in surficial sediments are still above acceptable criteria levels for aquatic ecosystems. In contrast to most metals, concentrations of selenium were slightly higher in the Gilbert Bay sediment site located in Farmington Bay near the Site discharge canal, concentrations of metals were high and showed a decreasing trend in recent sediments, but this core may be provided additional information. Additional sites in the Great Salt Lake indicated that metals were more concentrated at the end of the lake where the primary sources of contamination were located.

Introduction

Mining and industrial activities frequently release toxic metals directly to water or indirectly via atmospheric deposition. A notable example is the Great Salt Lake in Utah, which is located close to both major mining and industrial activities in a metropolitan area with extensive industrialization. Beginning in the late 19th century, air and water pollution in the region has been a major concern. Peterson (1985) and Varley et al. (1921; McPhean and Greg 2005) have documented the history of mining in the area. This mine was once the largest in the world, producing over 16 million tons of copper. Other metals such as silver and molybdenum have also been produced in significant quantities as well as zinc, lead, and cadmium. The smelter located on the shore of the Great Salt Lake

(Fig.), but other smelters in the Salt Lake area have also contributed to the problem. Not only much of the intermediate products were produced by the Murray smelter, located on the Jordan River 30 miles from the Great Salt Lake, is a Superfund Site because of contamination of lead that lasted from 1972 until 1982 (Keck and Lepore 1982). In addition to mining, the area contains several large mines to extract phosphate located in the Basin and Range watershed in the state of Idaho (Mars and Crowley 2002). The Snake River is the largest source of water for the Great Salt Lake. In addition to phosphate, other mines release significant amounts of selenium (Hamilton and 2005). Industrial activities in the Great Salt Lake metropolitan area have included pulp mills, power plants, railroad refineries, and petroleum refining and

Figure 1 Map of the Great Salt Lake showing the corner causeways, and small and large (1000 ft) wastewater treatment plant locations. The Kennecott Canyon porphyry copper mine (Kennecott)

manufacturing have released metals in Salt Lake watershed (The Forrester Group 2008).

The accumulation of metals near the lake has been measured utilizing sediment retrieved from the lake. The chronology of Kada et al. (1994) metal contaminant inputs from the DeWitt Creek Reservoir located just east of Valley View recent network of sediment

Figure 2. Aerial view of the Kennecott Copper smelter (lower right) and its tailings pond south of Gilbert Bay, Great Salt Lake the background. Photo 9 March, 2012.

remote sites have also been affected by metal pollution in the Snake River Valley. For example, remote Mirror Lake in the Uinta Mountains 100 km from the Salt Lake basin is also showing the early (1900s) paleolimnological paleolimnological record demonstrated unequivocally that these are paleolimnological atmospheric dust originating from smelters producing sulfur dioxide (Munsterstein et al. 2010; Reynolds et al. 2010) and that these are frequently deposited in lakes. Fossiliferous limestone and dolomite in the Uinta Mountains underlying quartzite bedrock offers little buffering capacity, but it from the west desert of Utah reaches these waters (Feldiss et al. 2008).

Despite this presence of metal contamination in the Great Salt Lake because bioaccumulation has not been a concern in this hypersaline abundant fish in its estuaries. However, a recent study indicates that metals through the food chain populations of migratory birds that utilize productivity of the lake to (Aldrich and Paul 2002; Cavitt 2007; Ve Cline et al. prep.) in a preliminary analysis (2007) and relatively high levels selenium and other metals in the brine shrimp and bivalves that migratory (Aldrich and Paul 2002; Wurtsbaugh et al. 2007) and high selenium levels, combined with a permit application by the Kennecott Copper selenium into the lake led to an extensive examination (UDW 2008) Naftz et al. (2008) documented excessively high levels of total and meth

Great Salt Lake, and this was followed by a coordinated study to assess this toxin in the Great Salt Lake (Nastys et al. 2009a; U.S. EPA 2010; W. Fitzhally), an extensive analysis of many metals and other toxins in the Great Salt Lake and completed that documented metals concentrations that were frequently exceeded (Waddell et al. 2009) caused detrimental effects on organisms (Macdonald et al. 2000)

To help understand the degree of metals contamination in the Great Salt Lake, a chronology of this contamination history was determined using sediment cores from the south arm of the lake (Gilbert Bay) and Gilbert Bay which receives significant loading of metals and nutrients from the city. The sediment cores allowed 200 years of metal deposition in the lake. Additionally, surface sediments were analyzed from five other sites of contamination. The results for Gilbert Bay show that the deposition of most metals peaked in the 1800s and peaked at high levels and has since declined. Selenium, however, continues to increase in the sediment record, as have most

Study Site and Methods

The Great Salt Lake is a 5000 km² basin system in Utah, USA (41°N, 112.28°W) bordered on its eastern and southeastern shores by the Snake River Plain over a million. The lake has been impacted by industrial and municipal effluents by transportation causeways that divide the lake into two bodies of water. The lake was divided in two by a railway causeway constructed in 1905, which restricts exchange of water and salts. However, salinity in the northern arm is normally at saturation. In the southern arm of the lake, Gilbert Bay, salinity is 2400 mg/L but lake depth, volume and salinity vary greatly with precipitation. Surface salinities in Gilbert Bay range from 1600 to 2800 mg/L. Elevation of the mean and maximum depths of Gilbert Bay is 10.1 m. Gilbert Bay receives an underflow of saturated brine from Gunnison Bay that passes through and fill material, so that ~50% of the southern bay is underlain by brine that has high concentrations of chlorides and sulfates and Wurtsbaugh (1990) provides a historical overview of salinity in Gilbert Bay and the lake's biota.

The two bays on the eastern shore of the lake are described in the Wasatch-Cache National Monument and can be characterized as estuaries with salinities ranging from hypersaline conditions, both spatially and temporally. Farmington Bay (10 km²) in the north is shallow, with a mean depth of only 1 m. It receives flows from the Jordan River that passes through Salt Lake City and by smaller creeks on its eastern side. Farmington Bay was joined on the north and south to Gilbert Bay, Utah, by a causeway constructed in 1952. In 1969 another automobile causeway was constructed to the southern tip of Antelope Island, thus rejoining Gilbert Bay when lake levels were low.

the northern tip of Antelope Island with a road bridge that allows water exchange between Farmington Bay and Great Salt Lake. In the 1980s when the lake reached an all-time high, the overflow of the automobile causeways has been to make Farmington Bay fresher, with spatially and temporal up from 0.1 to 0.2 m (Wurtsbaugh and Marsden 2006) intrudes from Gilbert Bay so that the northern half of Farmington hydro-sulfide rich deep brine layer (Blowcock and Smith 2012) in the NE has an area of 2.12 km² of only 0.6 m at mean (FAK 2010) in late 1960s interchange between Bear River Bay and Gilbert Bay was ponds and a bridge by the Great Salt (Becker et al. 1984) in the Bear River Bay receives flows from the lake's largest tributary, the Bear River, an runoff, but salinities can climb to three to five times and concentrates entered the bay from the adjacent Gilbert Bay (Serafini et al. 2007a)

In addition to the causeways that have modified the lake's changes have occurred in the Salt Lake City by Mormon pioneers in human population and accompanying industrial development on the rapidly: 8,000 in 1850, 90,000 in 1950; 1,150,000 in 2000 (Counties of Salt Lake Davis and Weber; Tiffany et al. 2007) during spring snowmelt, the constructed in 1885 to divert water from the Jordan River to Salt Lake City the wetlands bordering the southern edge of Farmington Bay (Fig. 1). In 1952 joined with the Goggin Drain so that flood waters (Deseret News 1952) An analysis of flows from 1975 to 1984 % average Jordan River's flow is diverted to the Goggin Drain (CH2M Hill 2012). of these flows Gilbert Bay are due to runoff when waste diluted. The first system in Salt Lake discharged raw sewage to the Jordan River, but conditions in the river were so bad that a Sewerage System was constructed by 1965 that discharges the River and discharges directly to Farmington Bay (Hooton et al. 2012) Northwest Oil Drain connected to the Sewerage System discharge industrial refineries and other in the NE part of Salt Lake City (Fig.). Because of this and other contaminants have accumulated

Figure Northwest Oil Drain and raw sewage in Salt Lake City. The Oil Drain joins the Salt Lake the lake at the south end of Farmington high-rise buildings of Salt Lake City are visible. The Wasatch Mountains are in the background.

Oil Drain, it is now an EPA Superfund Clean Water Group addition to the industrial activities of the growing city, the minimum contribution to the high metals loading to the lake. Water quality conditions in

Year	Event
1847	Mormon pioneers settle Salt Lake Valley.
1863	Copper mining begins at Bingham Mine; intensifies in 1873.
1873	Lake reaches high level (4211' ; 1283.5 m), but salinity only de
1885	Surplus Canal constructed that diverts flood flows of Jordan Riv
1889	First sewer line in SLC to the Jordan River (2.3 yd ³ /d. 0.8 flow was 0
1892	First smelter for gold, silver and lead.
1906	Agriculturists win lawsuit against four Salt Lake Valley smelters and arsenic.
1911	Outlet Sewage Canal completed to the Great Salt Lake (Farming River).
1922	The current Oil Drain - Sewage Canal to the Great Salt Lake co
1930	Farmington Bay Waterfowl Management Area constructed. Dikin sediments in wetlands.
1952	Goggin Drain connected to Surplus Canal so that spring floods of Record flood in Jordan River.
1952	South causeway to Antelope Island constructed to prevent raw s south end of Gilbert Bay when high lake levels flooded the sill t longer in Farmington before reaching Gilbert.
1959	Railroad Causeway completed that separates Gilbert and Gunnis but deep brine layer begins to form.
195	Three sewer districts formed in Davis Co. to discharge wastewa
1962	10 m ³ d ⁻¹ (70 million gallons per day).
1963	Lake reaches lowest recorded level (1277.8 m; 4192.2'). Deep end of Farmington Bay would have been just river/wastewater fl went.)
1965	Secondary treatment facility completed in Salt Lake City; discha
1969	Automobile causeway to Antelope Island completed, partially isd (4206.5 ft).
1970	Clean Air Act of US; 1977 significant increases in regulations.
1984	Automobile causeway to Antelope Island flooded by high water u
1985	Gilbert Bay reaches record high level (4208.85'; 1282.86 m); Sa
1992	Automobile causeway rebuilt.

Table 1. D important events that have influenced contaminants in the Gre

Farmington Bay, which received the majority of the wastewater discharge presumably degraded rapidly, although documentation provides support of raw and treated sewage discharge into Farmington Bay in the review of the sewage discharge water under Meide (1972). In the case of the outfall of the Sewerage was reaching swimming beaches at the Bay (Saltair) when the lake was high enough to permit water exchange with the Antelope Island. In 1952 an elevated roadway was constructed to prevent sewage from reaching the swimming beaches at Saltair.

Recent studies have shown that water quality conditions in the bay are marked by high phosphorus and nitrogen loading. Farmington Bay is hyper-eutrophic with phosphorus loading of 100 kg P yr⁻¹ and nitrogen loading of 2000 kg N yr⁻¹. Cyanobacteria blooms are common with concentrations of 141 µg L⁻¹ (Wurtsbaugh et al. 2008). Concentrations range from supersaturated throughout the water column with diel swings in photosynthesis ranging from 0.5 to 1.5 µg L⁻¹ (Wurtsbaugh et al. 2007). Temperatures in the shallow reach 30°C during the daytime in summer, and salinity is generally low. Phytoplankton in Farmington Bay can be limited by either nitrogen or phosphorus (Wurtsbaugh et al. 2006). However, the bay has had secondary treatment of human sewage in the bay (Crist et al. 2011). In 1988, we found hyper-eutrophic conditions at the Antelope Island Causeway where the lake was at a high water level. Total mercury concentration in Farmington Bay is 0.5 µg L⁻¹ (Naftz et al. 2009b).

Gilbert Bay, with recent salinities of 10‰, is productive throughout the year. The brine is composed of 5.5% Mg and 5% Na salts (Wurtsbaugh 1980). Oxygen concentrations are usually near saturation in the mixed layer below ~6.5 m. Temperatures are 24°C in summer and 10°C in winter. The pH is relatively stable (Wurtsbaugh and Marcarelli 2006). This bay is dominated by green algae and a few diatoms (Rushforth 1979; Wurtsbaugh and Marcarelli 2006; Wurtsbaugh et al. 2011). Concentrations vary seasonally, with winter concentrations of 1 µg L⁻¹ and summer concentrations of 10 µg L⁻¹. Phytoplankton biomass is high when grazing by mesozooplankton depresses the phytoplankton populations. Phytoplankton biomass is high when salinity is low and nitrogen fixation is high (Stephens and Gillespie 1976; Wurtsbaugh and Marcarelli 2006). It is estimated that nitrogen loading is high (1.2 yr⁻¹) with approximately 45% contributed by the outflow from Farmington Bay. Total mercury in the mixed layer of Gilbert Bay is 0.5 µg L⁻¹, but much higher concentrations occur in the deep brine layer (Wurtsbaugh et al. 2008; Jones et al. 2009; Wurtsbaugh and Wurtsbaugh 2009). Information is available concerning water quality but mean chlorophyll levels are 2.2 µg L⁻¹ (Wurtsbaugh et al. 2012) and selenium concentrations are ca. 0.5 µg L⁻¹ in the bay and total mercury concentrations in an adjacent bay are 0.5 µg L⁻¹ (Naftz et al. 2009b; Naftz et al. 2009a).

that are usually near saturation and a near absence of metazoan organisms in other bays, with a focus on microbial diversity (Pandel et al. 2011)

Table 2. Coring site locations and characteristics

Site Characteristics	Bay and Site Number							
	Farmington Bay			Gilbert Bay			Bear River	
	1	2	7	3	4	5	6	8
Coordinates	40.9142 -112.049	41.0584 -112.217	40.9317 -112.095	41.009 -112.439	40.8250 -112.297	41.0720 -112.428	41.2764 -112.351	41.3933 -112.127
Collection Date	17-Aug-09 17-Aug-09 25-Jun-10			18-Aug-09 19-Aug-09 20-Aug-09			21-Aug-09 8-Jul-10	
Station Depth (m)	0.15	1.01	0.68	7.35	7.8	7.94	0.12	0.7
Bottom Salinity (g L ⁻¹)	1	80	4	147	147	147	145	2
Secchi Depth (m)	>>0.15	0.16	0.38	0.7	3.8	2.15	0.5 (deeper site)	>0.7

Coring, Sectioning and Diatom sectioning were described in detail by C. & D. Strickland (1980). Briefly, cores were collected with a gravity corer with a 20 cm diameter tube at 10 sites in three of the bays August 2009 to July 2010. Site coordinates and depths at the time of collection are given in Table 2. Cores were processed in the field (2009) and returned to the laboratory (2010) and sectioned upright to the laboratory (2010) and sectioned with a Glew push rod extruder (Glew et al., 2001).

The locations of the nine coring sites are shown in Figure 4. Two sites were in Gilbert Bay (Site 3, 4) at depths > 7 m where a brine layer (mainly) is present. The other sites were at the south end of Farmington Bay. At low water levels this broad channel is partially disconnected from the bay (Fig. 4). At the time of collection Site 1 was only 0.15 km from the discharge of the Sewer Canal/NW Oil Field. At mean lake elevations of ca. 6 km from the discharge, low lake levels, Site 1 is better characterized as a narrow channel. The former Jordan River channel was at mean lake elevation of 1,280 m; 4,200 ft.) and would have been ca. 1 km from the discharge. At low lake levels, Site 1 would have mixed with the main Farmington Bay. Figure 4 Aerial photograph showing Farmington Bay and the location of the lake levels the sand sill to the north is inundated and the water would mix with the bay. The Site 1 core was taken when the elevation of 1,278.6 m (4,195 ft) was reached. April 2008 Gilbert Bay was at a level of 1,279.6 m. Photo by W. Wurtsbaugh. Site 1 is near

the fresh water inflows from the Central Davis Sewer District, the Jordan River after it has passed through the wetlands at the south inflows create strong salinity gradients of the bays with nearly fresh water and salinities of 12‰ at the northern end after the construction (Hayes 1971; Wurtsbaugh and Marnett 2006). Salinity gradient results in very diverse communities from north to south (Wurtsbaugh and Marnett 2006). Results for Site 1 should not be interpreted as being characteristic of the entire bay.

²¹⁰Pb dating of the cores is described in Oberly et al. (2012). Cores were freeze-dried and then counted at the University of Regina Environmental Quality Laboratory (Site 3) and University of Waterloo (Sites 4, 5) using gamma High Purity Germanium (HPGe) Coaxial Well Photon Detection System. ²¹⁰Pb activity was measured to identify the period of maximum fallout from testing (1959-63). Sediment to grain ratios were calculated using the CRS (constant model) (Appleby and Oldfield 1993). Accumulation rates were computed from output of the CRS model and Oldfield (1983) represent the mass of dried (sediments + salt) in each 0.5 dm² increment by which time represented in the Dates earlier than ~1875 CE (Common Era, formerly AD) were approximated using accumulation rates.

The dating chronologies for the three cores are shown in Fig. 5. Results are available in Leavitt et al. (2012). The Site 4 core in Gilbert Bay shows a peak in the 1960s. In the Site 3 core the peak occurred between 1920 and 1940 (based on Pb depth estimate), making the chronology for the site less reliable. We have relied more on the Site 4 core for interpretation of the historical patterns seen at Sites 3 and 4 were relatively similar (see Results). In the 1960s, but the peak was distorted in the surface sediments due to post-depositional mixing (see Leavitt et al. 2012). Of the ten cores collected, only 2 yielded usable ²¹⁰Pb chronologies, likely because in many of the shallow bays the sediments were homogenized so that useful temporal resolution was lost. We analyzed the upper 10 cm of sediments from five of these sites to provide an estimate of the Great Salt Lake.

Analytical Methods Sediment subsamples from each core were freeze-dried at 70°C until constant weight. Metal concentrations in the sediment were determined at the Utah Veterinary Diagnostic Laboratory (Logan, Utah). The nitric acid leachable mineral concentrations were quantified using inductively coupled plasma atomic absorption spectroscopy (ICP-AAS). Total materials were digested from subsamples on a heat block for 4 hours. Weighed sediment samples (~0.5 g) were digested in 10 mL of concentrated HNO₃. The digests were diluted 1:20 with 18.2 M HCl 5% nitric acid water, prior to analysis. This resulted in a matrix match to the standards and quality control. Higher mineral content high standard were diluted 1:10 in 5% nitric acid. Standard curves for all elements, except mercury, consisted of five points. Standard curves for mercury consisted of three points. A quality control (QC) test sample was analyzed with each day analytical accuracy.

sample had 50% of the known mineral specifications to pass. Any failed QC test was zero. A small number of samples for silver yielded. For these we assumed that concentrations were 80% of the detection limit. The cores had values just slightly over the detection limit.

The metal concentration in each core was adjusted for the dissolved in the interstitial water. Consequently, most of the data are on a dry weight basis. The salt correction was particularly important for the Bay cores with unconsolidated sediment and consequently contained a considerable amount of water. Salt content was measured by weight loss of thin slices of sediment in a desiccator. Salt content was then estimated by multiplying this amount by the water content (Table 2) using the assumption that diffusion of salts would bring the pore water overlying the surface of the Bay cores, the salt in the interstitial water for about 50% of the dry weight of material, so that the salt correction of metals in these Mesometals concentrations was to subtract background levels, and calculate enrichment indices for metals in more recent

Historical Production of Metals in Utah Production of many commercial metals of Utah were obtained from the Sulphur, Lead, and Silver mines of these minerals were produced in Salt Lake Valley or the Tintic/Mercur mining districts that are well known (Ege 2005) though small amounts of mercury have been mined in Utah may have originated from imported mercury used in amalgamation and subsequently from mercury released in the smelting process containing lead (Paul and Zehle 1996) well as from other sources of mercury. Consequently, as a metric to measure mercury use the amount extracted from the State is not ideal because of the multiple potential sources of mercury

Indices and Criteria The approach of Johnson, Boyle et al. (2004) and others have calculated indices that allow chronologies of multiple metal concentrations. Contaminant index throughout a core was calculated as the ratio of the concentration to the mean concentration in the sediments (Macdonald 2000). An Anomalous Index was calculated at the maximum concentration in the core divided by the mean concentration in recent sediments (relative to the mean background concentration observed in 1860). Because of the unusual chemistry and biota in many parts of the Great Salt Lake criteria have not been established for assessing the degree of impairment. Nevertheless, to provide some context for the data being presented in the Great Salt Lake sediments we have used the Freshwater Effects Concentration Index (FECI) to assess impacts on biota. The Probable Effects Concentration Index (PECI) like (MacDonald et al. 2000)

Although these metrics are used as a proxy, they do mean those criteria can be the Great Salt Lake ecosystem, especially in Gilbert Bay where salinities and adapted biota are present

Dating chronologies for Site 1 in Farmington Bay, Utah, show lead activities (disintegrations per minute, dpm) uncorrected. The middle row shows ²¹⁰Pb activity and the last row shows estimate on variance ²¹⁰Pb counts. From Leavitt et al. 2012.

Results

Historical changes in metals concentrations

Gilbert Bay analyses of both cores in Gilbert Bay indicated that in the sediment record in the late 1800s and early 1900s coincident with mining in the 1950s and have since declined (Fig. 1). For example, both copper concentrations rose to a peak of 1% before the onset of commercial production in the 1950s when copper extraction reached 250,000 metric tons. Since the 1950s, concentrations of sediment metals have declined; however, in surficial sediments, they are still higher than background levels. This has occurred despite an overall increase in copper production in the

Figure 6. Left frames: Concentrations of Cu, Hg, Pb, Cd, Zn, and Ni in sediment cores from two coring sites in Gloucester Bay, Massachusetts. Dotted vertical lines indicate Threshold Effects Concentrations (TECs) for these metals in freshwater ecosystems. Right frames: Metal profiles from geological surveys (2011). Note that although zinc was mined along a commodity until the early 1900s (Krahn, 1990), it is not a

the trend

was more variable. Background mercury concentration was around $0.1 \mu\text{g/g}$ until the 1870s and increased sharply in the 1870s and 1880s (Fig. 5). Mercury concentrations in the sediments from Site 3 peaked in 1920, and have declined significantly to levels in the 0.5-2 cm sediments. At Site 4 the overall trend is similar with a much more irregular decline over the last half century.

Lead and zinc concentrations had similar trends in Gilbert Bay (Fig. 6). Both had low background concentrations of 7 (Pb) and 45 (Zn) $\mu\text{g/g}$ in the late 1800s and, coinciding with the onset of lead and zinc production. Concentrations in the sediments at Site 3 and Site 4 (at depths far above background and subsequently dried) were similar. Although lead and zinc concentrations were higher at Site 4 than at Site 3. Although lead and zinc concentrations have declined to background levels, and although sediment concentrations have declined, concentrations remain well above background at both sites.

In contrast to most metals, concentrations of selenium and arsenic increased in the sediments of Gilbert Bay. Background concentrations of selenium were $0.1 \mu\text{g/g}$ at both sites. Concentrations did not increase significantly and only have remained relatively constant or increased slightly ($1 \mu\text{g/g}$) in recent sediments. Background levels of arsenic were around $1 \mu\text{g/g}$ during the 1800s when selenium was increasing. Concentrations of arsenic have increased significantly at both sites.

An indicator of fluvial transport (Sohmer et al., 2012) of change marked in the cores (Appendix 2). This suggests that much of the deposition in Lake has been by atmospheric deposition rather than by riverine

Figure 7. Concentrations of selenium and arsenic from two sediment cores from Salt Lake. Concentrations are expressed as dried dry sediment.

aluminum concentrations were similar, did show some parallel changes with approximately 1910, but this pattern was not evident at the other two sites. Farmington Bay- (Silted) sedimentary record of metals in the Farmington Appendix differs considerably from the patterns seen in Figure 6 & 8 of Gilbert Bay. The estimated background for the core sample Farmington Bay metal concentrations are similar up until the early 1950s when there was an increase in most metals. For example, background copper concentration was 11 µg/g in the early 1950s, peaked at concentrations of 200 µg/g in the late 1950s and then stabilized at concentrations near 100 µg/g (Ag, Cd, Cr, Cu, Hg, Mo, Pb, Sn, and Zn) (Appendix 1c). Copper, mercury, and lead are some of the most toxic metals and their effects concentrations in the upper 10 cm of sediment are similar to those in Farmington Bay and that in other bays. It is likely that the sediment record in Farmington Bay was not preserved prior to the 1950s, thus yielding a record of pristine conditions in the bay in the first half of the century (see Discussion).

Figure 8 shows concentrations of copper (A), mercury (B), lead (C) and cadmium (D) in the south end of Farmington Bay. The arrow on the left shows the date of completion of the industrial effluents into the bay. Vertical dotted lines indicate the Threshold Concentrations (TEC) and Probable Effects Concentrations (PEC) of the onset of metal pollution in Farmington Bay is problematic.

Metal accumulation rates in sediments are a function of sedimentation rates. Although the metal concentrations in Gilbert Bay had the lowest sedimentation rate, Farmington Bay had a higher rate (Figure 9). These rates, when combined with the metal concentrations in the sediment, show that the metal accumulation rates in a square centimeter of lake sediment at Farmington Bay varied spatially and temporally. Salt Lake, the general patterns of metal accumulation reflect the trends in the Great Salt Lake. One notable exception is the high accumulation rates at the Bay sites in the late 1950s and early 1960s. In contrast, mercury accumulation rates were relatively similar to other metals around 1900. In contrast, mercury accumulation rates were relatively similar to other metals around 1900.

Farmington Bay than in Gilbert Bay, 1950s (Fig. 6). The accumulation rates of the two Gilbert sites were similar throughout the data period, and Farmington Bay sediments also accumulated at this rate. The sediment accumulation rates were relatively similar in the three sites throughout the period, particularly in recent sediments.

Contamination Indices The Contamination Indices of the metals and concentrations presented in concentrations shown in Fig. 10 plots show that most of the trends are dependent on the mining districts, and if the sum of the metals were Gilbert Bay's sedimentary concentrations. Both the metals associated with porphyry copper and gold deposits and Mercur gold mining districts are shown in Fig. 10. Copper, silver, and lead show similar concentration peaks that were 2 to 4 times higher than background concentrations. Silver and copper peak in the relative abundances in the early 1900s.

Figure A. Estimated solids (sediment + salt) accumulation rates in Gilbert Bay and one in Farmington Bay. These were used to estimate lead and selenium (D) deposition in the sediments of Farmington Bay. In Gilbert Bay sites solids accumulation rates were 1.08 kg m⁻² in 2003, 1.74 kg m⁻² in 1986, and 2.00 kg m⁻² in 1993. In Farmington Bay, three phases were 1.93 kg m⁻² in 1930, 1.93 kg m⁻² in 1963, and 2.00 kg m⁻² in 1993. The accumulation rates are dependent on the mining districts.

The sediment concentrations of metals (Pb, Zn, Cu, Ag, As, Cd, Sb, and Hg) from the plus associated with the Tintic, Park City and Bingham Canyon showed a temporal congruence in their relative abundances. Lead and cadmium had the highest relative increases with peaks about 30 times above background levels in the 1940s. The other metals also peaked in the 1940s, whereas zinc increased only 4 times above background levels. The temporal pattern for lead and cadmium is similar to those for the other metals, but only in the 1940s. In the porphyry and sediment from Bingham Canyon and Mercur, the concentrations of metallic replacement deposits have increased in sediments since the 1940s and 1950s.

Figure 1. Maximum Contamination Index (ratio of maximum concentration in the sediment core to the Current Contamination Index (surface concentration/background concentration)) at three coring sites in the Great Salt Lake based on the 10-year running means shown in Figure 10. The figure now depicts how concentrations of metals in Gilbert Bay are now considerably lower than during the 1950s and 1960s.

The present conditions are summarized in Figure 10. The Current Contamination Index, or the amount of a metal in the sediment relative to background conditions (Fig. 10). When viewed in relation to the Maximum Contamination Index, the Current Contamination Index indicates that both selenium and arsenic are the highest levels observed in the area, suggesting that inputs are continuing, or that metalloids are more mobile than copper and lead, which had some of the highest Current Contamination Indices, have reduced significantly, surface sediment concentrations in the surface sediments of Gilbert Bay to a level of 42% of the highest concentrations observed in the 1950s and 1960s.

For the Farmington Bay Current Contamination Index, the Current Contamination Index shows that there has been a relatively decrease in the concentrations of arsenic and molybdenum are the only ones that have declined in current contamination. In fact, the main reason for the decline in arsenic and molybdenum concentrations is that they have declined below the Maximum Contamination Index level. The decrease in concentration occurred in the mid-1950s following the recovery from that spike in concentrations. The Current Contamination Index for arsenic and molybdenum concentrations have maintained relative concentrations in the 1950s and 1960s (Fig. 10).

Table 3 Average concentrations of metals in the top 10 cm of cores taken in three bays of Great Salt Lake. Threshold effects concentrations (TECs) and Probable Effects Concentrations (PEC) (McDonald et al. 2000) are also shown. For silver (20,000 mg/kg) in Washington waters is shown as a TEC. For selenium (100 mg/kg) in the Department of Environment's "toxicity threshold" are used. Concentrations exceeding the TEC numerals, and those exceeding the PECs are underlined. Note that these are shown only to provide comparison with criteria developed for fresh water. Indicative of hazardous concentrations in Great Salt Lake sediments.

Metal	TEC	PEC	Gilbert Bay			Farmington Bay			Bear River	
			3	4	5	1	7	2	6	9
Metals exceeding freshwater threshold effect concentration										
Selenium	1.0	4.0	<u>4.5</u>	<u>4.9</u>	<u>4.3</u>	2.4	2.1	3.6	1.2	0.1
Copper	32	149	102	<u>207</u>	91	145	132	47	16.4	14
Arsenic	10	33	23	<u>47</u>	18	19	21	14	7	5
Mercury	0.18	1.06	0.11	0.42	0.30	0.38	0.66	0.20	0.05	0.1
Cadmium	1.0	5.0	1.1	2.4	0.7	2.8	2.5	0.9	0.4	0.1
Lead	36	128	31	58	21	<u>130</u>	83	29	19	1
Zinc	121	459	75	125	47	264	205	76	46	3
Other Metals										
Cobalt			3	4	2	5	4	2	4	4
Chromium	43.4	111.0	8.5	11.5	5.9	35.3	23.1	7.5	9.3	7.5
Molybdenum			32.6	16.9	21.6	1.2	1.1	20.9	0.4	0.1
Nickel	22.7	48.6	9.8	14.3	6.5	12.7	13.8	8.1	13.3	9.5
Antimony			0.40	0.64	0.62	0.04	0.06	0.48	0.03	0.1
Silver			0.02	0.1	<0.03	1.9	2.0	0.1	0.1	0.1
Tin			0.77	1.65	0.62	2.76	0.06	0.48	0.03	0.1
Titanium			0.39	0.34	1.40	0.43	0.35	1.54	0.49	0.1
Vanadium			13.7	19.7	9.7	21.8	20.6	11.4	9.6	8.5

Metal concentrations in surface sediments

The surface sediment data from the Farmington Bay and Gilbert Bay have concentrations of several metals that are above the established freshwater criteria. Farmington Bay is relatively uncontaminated. From the 3-cu Arpent ecosystem health project, the most relevant metal concentrations were in the surface, as they are the most influence diffusion into the water column. Selenium and copper exceeded the freshwater threshold effects concentrations at all three sites in Gilbert Bay, and exceeded the freshwater Probable Effects Concentration in Farmington Bay, but never exceeded the PEC concentration. Selenium in the sediment

the TEC at one site. Copper and arsenic concentrations exceeded the Farmington Bays and Bear River Bay. Mercury was also relatively high in of Gilbert and Farmington Bay, but concentrations did not exceed the Bear River Bay had relatively low levels of this zinc and cadmium concentrations above TEC levels at one or more sites in Gilbert and Farmington Bay.

Copper and arsenic concentrations were higher at sites close to industrial sources than at sites further from industrial sources. Surface metal concentrations were higher at Site 4 which is close to industrial sources in the Salt Lake Valley than at Sites 3 and 5. This was also true for nearly all the metals than did Sites 3 and 5. This was also true for nearly all the metals than did Sites 3 and 5. There was a consistent gradient for all of the metals that were above the NW Oil Drain discharge and closer to smelters having the highest concentrations which is also at the south end of the lake with the lowest concentrations at Site 2 and of the Bear River Bay at the northern end of the lake had the lowest metals measured.

Figure M2. Mean surface concentrations of copper (Cu), nickel (Ni), and lead (Pb) at eight sites in the Great Salt Lake expressed as a percentage of the effects concentrations (PEC) developed by the National Academy of Sciences (NAS, 2000).

2014) This dense brine layer is frequently present below a depth of ~1 m, where brine reaches³, with a high salinity higher than that of most algal (Goldschmidt and Plafotriell 2009). Since most metals normally reach lake sediments as part of the process, the presence of the deep brine layer may have caused some of the mineralization would release it to the dissolved form. The deep brine concentrations of particulate organic carbon, as well as very high concentrations (Tank and Dodds 2003; Wurtsbaugh and Wurtsbaugh 2004) give some support for this hypothesis. Wurtsbaugh and Wurtsbaugh (2004) found that about 40% of the deep brine may be entrained into the upper mixed layer each year, which could result in the sediments. Cores taken by (2010) in the Uinta Mountains lakes from smelting activities did not record decreases in copper comparable to Lake. Additionally, most metals in the Great Salt Lake dates of approximately 1950 (Site 4; Fig. 10), before the advent of the railway and close to the time of construction of the railway causeway in 1950 support for the hypothesis that the deep brine layer may play a role in the sediments. However, more research will be necessary to determine the hypothesized mechanism.

Like many of the metals, mercury concentrations in Gilbert Bay have been declining from the highest levels observed in the 1970s. The decline at Site 4 has been attributed to atmospheric and riverine inputs to the Great Salt Lake is continuing and may be enhanced by gold mining and industrial emissions from coal power plants in central Utah (Nafiz et al. 2008). However, the atmospheric input to the lake is not abnormally high compared to the United States (Smith 2003; Peterson and Ghassini 2008) suggested that decreases in overall mercury concentrations suggest that the high mercury levels found in the lake (Nafiz et al. 2008) are at least partially due to early mining activities (Nafiz et al. 2008) so found decreasing mercury concentrations in a core collected in Gilbert Bay that were comparable to the declines in the lake that this may be a general phenomenon, at least for the deep areas of the lake.

The reason for the slightly higher and more irregular pattern of mercury concentrations in the Gilbert Bay Site 4 core than in the Site 3 core is that periodic releases of sediment from the tailings pond near shore of the lake have contributed irregularly to the metals load concentration. Site 4 is located at the south end of the lake ~13 km from the tailings pond, which is located 37 km to the north. The tailings pond is located 4.4 km from the shore, although it is not clear how much material from the pond (EPA 2002) it has contributed. Additionally, in 1965 Kennecott exposed by a dike that contained 536,000 m³ of tailings material. The dike was destroyed by two years, and the materials (EPA 2002) from the tailings materials at the pond can be arsenic, 240 kg and 16 kg of this material was spread over the southern area of Gilbert Bay, it would have only deposited a small amount of material on the shore (EPA 2002).

also contribute some metals to the southern end of the lake (particularly this is unknown).

In contrast to most metals, selenium and arsenic concentrations are either stable or showing a significant increase in both the Mercurio and ores of western Utah. Selenium is chemically anomalous in the porphyry copper deposits in the New and vicinity. Selenium is also released in the Bear River watershed that drains phosphate mining in the mountains (Mars and Crowley 2003, Hampton and Gupta 2005). In recent years (Meyers and Thackeray 1990) contributions from this source may be significant. However, Nafziger (2009) found that only 25% of the riverine selenium load in the River, and 75% were from the Salt Lake watershed, particularly associated with the Kennecott Mine tailings ponds. Arsenic and selenium activities, as demonstrated by accumulation in mountain (Moser et al. 2010; Reynolds et al. 2010) tailings (Evans 2002) consequently, increased activities in the Great Salt Lake are the predominant source of this contamination.

The Farmington Bay metal core taken from the south end of the bay also showed significant levels of metal contamination, but the chronology (Bay 13A) is not consistent with known periods when contamination occurred. The chronologies shown in Figure 8 emphasize little or no contamination in Farmington Bay from the late 1800s until the 1960s, when concentrations of metals rose suddenly to high levels. However, the Gilbert Bay core (Kada et al. 1994; Moser et al. 2010) and the Utah Lake core (Kada et al. 1994) show widespread deposition of metals from the Salt Lake in the early 1900s. It seems improbable that Farmington Bay is a direct recipient of metals from the lake.

Figure A-3. Comparisons of lead, a total algal pigment, and the sediment in the Farmington Bay core, and in *Siphonocapsa* chironomid species richness and a biotic index in the Farmington Bay head capsule. For the biotic index (D), the earliest estimate (1841) was from the head capsule. Arrows show the timing of industrial activity in Farmington Bay, and in changing the hydrology of the lake.

discharges near Site 1, and was contaminated with lead, arsenic, and other metals that operated from 1872 until 1949. The Northwest Channel, which was used to convey stormwater flows, industrial stormwater discharges, and sewage since its construction in 1922. The canal is currently an E-lead, copper, and arsenic canal. The Forrester Groves Sewer Canal also connects to the City Canal which drained industrial areas of much of the area into the Oil Drain did likely increase in the late 1940s (and as late as 2009) but this can explain the lack of metals in the core that should have been there from atmospheric contamination occurring from the Clear Lake Refinery. The organic matter accumulation can influence the mobility of metals in the sediments (Boudreau, 1999). However, Farmington Bay was reportedly highly organic due to sewage into the south end of the bay (V. D. Smith and D. N. B. Smith, 1972). Like had binding sites as automobile causeways to Antelope Island in 1960 construction may have contributed to metal increases in the sediments by reducing the increasing algal (Healey and Hendrickson, 1980). Additionally, the discharge of Gilbert Bay via the Goggin Drain that began in 1952 may have reduced the relatively high quality water. Measurements of a core from Site 1 indicate that the sediments rose from 5% carbon in 1950, and then more to 9% by 1960. In the 1950-2000 period (P. Leavitt, unpublished data). This suggests that the carbon after 1950 that could have increased metal retention to the extent that they are not. Additionally, metals are relatively immobile in alkaline environments (Belzile et al., 2004) those in the Great Salt Lake, especially with increases in high and metal sulfide precipitation (Cahoon and Nriagu, 2000). They analyzed a sediment core from the south end of Farmington Bay and found that there was a significant difference between the 1950 and 1960 data. The resolution of the analysis was insufficient to resolve the discrepancy in metal concentrations between the two cores. In an additional core they took in Decker Lake, located near Farmington Bay, the River yielded similar results (Naftz et al. 2000; Naftz, personal communication). It is unclear, but it is not likely that the sediment core they analyzed showed

The sudden increase of metals in Farmington Bay in the 1950s is consistent with the increases in eutrophication metrics (chlorophyll, diatoms, etc.) in the 1950s (Healey and Hendrickson, 1980). The macroinvertebrate community in Farmington Bay did not increase significantly until after 1960, when the increases began much earlier in Gilbert Bay (Figs. 13b, c). The Bay prior to 1960 in purple sulfur bacteria and cyanobacteria fossils (Healey and Hendrickson, 1980). The majority of eutrophication parameters did not date. Similarly, the benthic invertebrates in Farmington Bay had not increased (Fig. 13d). These delayed responses can be explained by the fact that the earlier part of the century because: (1) most nutrients and organic matter were a few kilometers from Site 1 before being advected into Gilbert Bay, and

(Lucin Cutoff) , and gene concentrations higher encountered at the two River Bay if the reason difference is not clear, but site was near them, and it might have had local cor the locomotives.

In Gilberts Bay face sediment found that most metals Threshold Effects Concentration copper, arsenic and me Probable Effects Concentration. However, these concentrations in deep area of the lake are no macroinvertebrates anoxic, reducing conditions (Cotillo 1980; Bioeconomics 2004) movement of the metals from the brine layer into strata that

Figure 4 depicts total mercury⁻¹ near the outlet of the CSW (Sewage Drain) described by Sorensen et al. 1980; Bioeconomics 2004. Our Site 1 is shown with a red star. Our core was located in a structure of (and other metals).

the food web be mixed.

dependent on internal waves (seiches) that can suspend sediments contacts the bottom (Bessie et al. 2009). Usually, when the lake reaches elevations, the deep brine already at this stage a plume of brine exposing the metals in the deep sediments. An additional factor limited coring is the vertical distribution of metals. The sediments might be more vulnerable to turbulence that could homogenize the concentrations of most of the metals to benthic invertebrates and brine water interface. Currently, although we noted marked decreases in most metals in the surficial sediments, these decreasing profiles in sediments in shallow areas of the lake (Hawes et al. 2009) did not find marked differences between sites on the deep offshore and those in shallow water. However, sampling, however, was with a Ponar dredge 10 cm into the sediment (Personal communication), and thus would have averaged metal concentrations that may have been several decades of deposition. If the target of investigation, care should be taken to standardize the thickness of surface samples so that their concentration is representative of the metal concentration that the biota would be exposed to.

The primary invertebrate Bay that would be exposed to the metal brine flies which are toxic to (Bixen et al. 2004). Frequently, the fact that

metals in Gilbert Bay s... Probable Effects of Freshwater... organisms necessarily a direct... bioaccumulate metals and transfer them into the birds. Analyses on the... of selenium and mercury bioaccumulation in the brine flies living on... shown significant bioaccumulation in the lake (Wurtsbaugh 2009; Wurtsbaugh et al... However, stromatolite and benthic sediment communities may function... applied to extending this earlier work to... Farmington Bay... a much wider diversity of... adapted to fresh water, a... concentrations of metals in those sediments could potentially impact... Effects Concentration Probable Effects Concentration... However, since the spatial... extent of sediments in Farmington Bay with high metal... Some estimates... 1988) the effects may be localized.

Conclusions

The Great Salt Lake next to a major... industrial... have been very... contaminated with a variety of metals. Despite... in the 1950s, most metal concentrations... result of... (1) decreased mining... (2) removal of lead from automotive gasoline, and (4) other... deep brine layer starting in 1969 also likely has reduced... there have been... decreases... copper, mercury, cadmium, zinc, selenium and arsenic... Above-Threshold Effects Concentration... stations in Gilbert and Farmington Bays. Bear River Bay, although... appear to... The... Great Salt Lake may be relatively resistant to a variety of pollutants and... may not be applicable... transfer metals to... birds that depend on... Additional research will be needed to determine... poorly studied metals in the lake (Cu, As, Cd, Pb and Zn) might be... common... Notwithstanding the declining levels... and selenium are either stable or increasing... metals... insure that they do not increase to even higher levels.

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Appendix 6: Salt Lake Bay (Site 3) metal concentrations in the sediment core from the Great Salt Lake. These concentrations are reported as per gram of dry sediment. To calculate the actual values measured in the dried sediment+salt mixture, multiply concentration

Salt-Corrected Concentration (ppm)		Ag	Al	As	Be	Cd	Co	Cr	Cu	Fe	Hg	Mo	Na	Ni	P	Pb	Sb	Se	Sn	Sr	Tl	V	Zn
2003.50	0.25	0.52	0.022550	15.0	0.15	0.70	1.78	5.7	65.43627	0.1214	0.034838	5.8	540	18.60	387.4	18	0.46	187	0.31	8.5	48		
1993.20	0.75	0.52	0.026071	31.8	0.41	1.45	4.41	11.3137	98966	0.1050	4.282045313	7.1510	44.40	406.4	85	1.08	451	0.46	19.0	10			
1997.51	0.25	0.55	0.016108	29.6	0.45	1.36	4.51	11.7144	19353	0.1158	2.28087414	6.1419	43.90	217.4	36	0.92	511	0.43	19.0	10			
1995.81	0.75	0.59	0.076556	30.3	0.49	1.75	4.85	12.7222	410010	0.1545	4.48659815	7.1418	51.70	137.3	72	1.19	543	0.54	21.7	12			
1993.22	0.25	0.52	0.026144	27.0	0.45	2.08	4.72	12.7238	29625	0.1962	3.823505116	2.1345	60.00	427.5	18	1.42	644	0.58	23.4	13			
1990.62	0.75	0.44	0.024696	20.6	0.41	1.51	3.73	9.7	159.87256	0.1679	7.87283713	0.1058	46.40	475.5	32	0.93	356	0.47	19.2	10			
1983.43	0.25	0.47	0.214419	20.0	0.32	1.43	3.75	11.3162	37042	0.1465	1.789880112	9.1255	44.30	325.4	33	0.98	346	0.41	18.9	9			
1985.33	0.75	0.49	0.244690	19.8	0.30	1.44	3.76	10.6172	57461	0.1465	1.789880112	9.1255	44.30	325.4	33	0.98	346	0.41	18.9	9			
1980.24	0.25	0.52	0.335259	20.8	0.37	1.72	4.31	12.4183	98540	0.1766	7.880799314	5.1236	61.40	350.3	74	1.42	454	0.55	22.5	11			
1974.04	0.75	0.54	0.355774	22.8	0.41	1.99	4.59	12.6206	39402	0.1846	4.830030015	5.1358	61.40	350.3	74	1.42	454	0.55	22.5	11			
1965.35	0.25	0.57	0.526528	26.5	0.45	3.18	5.29	13.9335	210608	0.2437	3.22987717	2.1234	87.20	157.3	18	1.82	749	0.77	27.5	15			
1955.65	0.75	0.60	0.466688	24.8	0.46	3.17	5.29	15.4287	710252	0.2841	4.82202717	3.1273	86.70	531.3	60	1.83	645	0.68	27.2	14			
1943.46	0.25	0.67	0.577031	27.2	0.48	4.17	5.25	16.4364	49847	0.2660	6.20445517	7.1142	108.40	677.3	56	2.08	619	0.90	24.6	15			
1942.16	0.75	0.73	0.551110627	29.0	0.47	3.78	5.09	17.2422	910984	0.2972	2.814552918	0.1059	108.31	196.3	57	2.35	811	1.09	23.7	18			
1934.87	0.25	0.76	0.496807	32.8	0.49	4.79	5.43	17.0461	011041	0.3073	3.11053718	3.1026	145.20	844.3	47	2.61	1168	1.23	24.1	17			
1927.67	0.75	0.79	0.425794	29.4	0.42	4.67	4.53	13.3367	59588	0.3358	6.511247916	9.905	114.50	633.2	70	2.25	1662	0.98	21.4	17			
1913.98	0.25	0.81	0.414982	29.9	0.42	3.68	4.02	9.2219	88044	0.5228	4.891798	15.5761	125.90	555.2	31	1.44	2335	0.55	18.7	14			
1912.38	0.75	0.83	0.375003	17.9	0.38	1.59	3.58	7.3221	18323	0.3411	4.488246	16.1693	95.20	0.84	1.65	0.96	2125	0.36	15.2	12			
1903.99	0.25	0.83	0.495426	16.2	0.43	1.53	4.00	7.9	186.58712	0.3811	5.878054	16.7675	119.40	371.1	68	1.08	1940	0.34	16.3	14			
1901.59	0.75	0.84	0.355878	12.3	0.48	1.01	3.86	7.6	72.89289	0.38	6.2080235	15.6619	108.90	119.1	54	0.62	1819	0.24	15.0	11			
1897.00	0.25	0.84	0.346281	11.6	0.57	0.92	4.04	8.2	28.09765	0.38	5.2577513	15.9660	104.40	0.95	1.55	0.51	1715	0.23	15.5	10			
1892.90	0.75	0.85	0.155981	10.7	0.45	0.76	3.84	7.9	20.09029	0.52	3.1177232	15.5596	94.10	0.106	1.67	0.44	1590	0.19	14.6	8			
1883.01	0.25	0.86	0.025307	9.8	0.37	0.43	3.44	7.3	12.58165	0.21	2.4465614	10.0562	33.90	0.058	0.92	0.33	1731	0.23	14.3	46			
1881.01	0.75	0.85	0.015329	9.3	0.39	0.48	3.35	7.1	16.28487	0.30	2.6575776	15.3563	55.60	1.29	1.08	0.34	1739	0.19	13.6	57			
1874.02	0.25	0.85	0.015703	11.0	0.45	0.27	3.61	7.6	11.48657	0.13	2.6874745	14.7522	13.10	0.059	1.06	0.29	1578	0.20	14.2	41			
1867.02	0.75	0.85	0.015794	12.0	0.45	0.23	3.58	7.8	12.688520	0.08	2.7871609	14.3513	7.0	0.059	0.86	0.28	1532	0.20	14.0	42			
1860.03	0.25	0.85	0.015759	14.9	0.49	0.26	3.73	8.0	10.99013	0.28	3.9176238	11.1548	7.0	0.129	1.22	0.31	1636	0.24	14.8	44			
1853.13	0.75	0.85	0.015576	14.5	0.43	0.23	3.50	7.7	10.28706	0.09	4.1970966	11.8524	6.5	0.176	1.09	0.29	1646	0.26	14.0	40			
1852.14	0.25	0.86	0.015633	20.1	0.54	0.26	4.09	8.7	11.39222	0.07	4.7570319	14.8615	6.0	0.105	1.28	0.31	1693	0.26	15.8	47			
1843.14	0.75	0.86	0.015221	18.0	0.45	0.45	0.27	3.8	7.7	8.8774	0.36	5.1569500	15.2575	6.2	0.290	1.44	0.28	1718	0.28	15.0	43		
1844.25	0.25	0.87	0.015383	18.6	0.52	0.34	3.80	8.4	11.88866	0.34	5.3267822	16.0651	7.2	0.289	1.32	0.34	1739	0.28	15.8	46			
1840.25	0.75	0.87	0.015696	17.4	0.45	0.25	3.59	7.9	11.68921	0.06	4.1758074	15.5589	7.1	0.162	1.56	0.29	1714	0.29	15.0	43			
1833.36	0.25	0.87	0.015402	14.7	0.39	0.30	3.41	7.8	11.18535	0.05	3.3361648	10.0534	7.9	0.092	1.27	0.32	1736	0.43	15.5	42			

Appendix Gilbert Bay (Site 4) metal concentrations in the sediment core from the Great Salt Lake. These concentrations are corrected for the amount of dry sediment. To calculate the actual values measured in the dried sediment+salt mixture, multiply concentration per gram of dry sediment.

210Pb Yr	Corr Sedim Mid (fract of dry)	Ag	Al	As	Be	Cd	Co	Cr	Cu	Fe	Hg	Mo	Na	Ni	P	Pb	Sb	Se	Sn	Sr	Tl	V	Zn
2002.00.25	0.500	0.085260	41.8	0.42	2.24	4.03	11.1	193.88003	0.2015	0.3320824	14.01429	54.70	775.5	20.1	49.458	0.87	18.7	11					
1994.80.75	0.570	0.055942	51.7	0.53	2.51	4.56	11.82	19.39171	0.6318	0.24710314	5.1458	61.80	510.4	68.1	81.471	0.81	20.6	13					
1983.21.25	0.500	0.025867	49.7	0.44	2.53	4.51	12.0233	4.8835	0.2319	0.322393214	7.1414	62.30	503.4	76.1	79.501	0.79	20.9	13					
1971.31.75	0.570	0.406024	41.2	0.53	3.22	5.15	15.0295	5.9253	0.9144	0.324530718	6.1391	84.10	897.4	24.2	27.564	1.13	25.2	15					
1963.42.25	0.520	0.587078	32.5	0.55	5.12	6.15	19.6450	6.1280	0.4076	1.121707820	9.1367	150.81	352.4	86.3	33.625	1.51	28.6	18					
1955.52.75	0.570	0.477698	40.3	0.64	9.74	6.81	21.7490	0.12694	0.4978	0.305478321	1.1297	262.11	558.5	52.4	33.926	1.81	29.1	20					
1945.03.25	0.730	0.476512	38.4	0.56	7.27	5.75	16.3369	1.0758	0.6644	0.730643918	5.1117	204.01	112.3	64.3	53.1771	1.47	23.4	21					
1935.53.75	0.780	0.466873	39.2	0.57	9.54	6.37	19.8493	0.31395	0.4267	1.02315519	4.4167	242.70	294.4	46.4	23.906	1.65	25.3	23					
1923.84.25	0.340	0.313490	23.0	0.26	5.25	2.57	6.9	204.75537	0.2711	0.9272676	9.6	607.112	60.072	1.60	1.161075	0.66	11.3	90					
1921.14.75	0.390	0.242647	18.6	0.21	1.68	1.97	5.2	164.14375	0.31	9.1641223	6.9	391.62	70.325	1.21	0.89	854	0.58	8.6	73				
1915.45.25	0.380	0.213806	19.5	0.30	2.62	2.79	6.6	247.86240	0.34	7.0256260	9.1	543.124	50.103	1.68	1.151068	0.54	11.6	11					
1909.75.75	0.360	0.214976	18.1	0.40	2.06	3.71	7.9	326.58211	0.48	8.4162339	13.9	688.156	40.198	1.62	1.441273	0.62	14.1	17					
1903.16.25	0.360	0.244829	13.6	0.39	1.73	3.37	7.0	167.17543	0.38	5.6158897	11.8	600.157	10.081	1.31	0.891311	0.45	13.1	12					
1895.56.75	0.370	0.715792	13.2	0.51	1.48	4.06	8.3	104.79397	0.44	5.1556261	13.2	668.163	10.058	1.28	0.801778	0.43	15.7	12					
1889.67.25	0.370	0.165288	7.4	0.37	0.56	3.31	7.1	19.89001	0.28	4.3356751	10.0	544.61	30.058	1.01	0.372031	0.26	13.3	53					
1882.77.75	0.370	0.135499	8.5	0.45	0.45	3.60	7.8	19.99073	0.18	3.8057672	16.2	595.31	20.069	1.33	0.391817	0.29	15.1	48					
1874.68.25	0.370	0.066637	10.5	0.49	0.34	4.11	9.4	18.110231	0.14	2.3958025	14.4	645.14	70.034	1.39	0.381188	0.30	16.7	52					
1865.48.75	0.370	0.146353	12.0	0.52	0.34	4.18	9.0	15.810555	0.10	3.5158088	16.3	619.10	90.057	1.15	0.371392	0.37	15.1	51					
1845.69.25	0.370	0.026051	12.7	0.47	0.37	3.91	8.4	13.810236	0.19	2.8559084	13.1	568.11	00.114	1.05	0.311578	0.33	14.3	47					
1824.99.75	0.380	0.026055	13.3	0.50	0.31	3.53	8.3	13.210063	0.10	2.8456427	13.3	570.8	3.0	1.250	0.95	0.301555	0.79	13.5	47				
1810.10.25	0.380	0.035762	13.5	0.44	0.25	3.36	7.8	11.49503	0.05	1.7752081	10.2	554.7	5.0	0.045	0.88	0.271859	0.36	13.0	47				
1795.30.75	0.380	0.015039	11.7	0.48	0.22	3.14	7.0	9.2	8623	0.03	2.3152467	9.1	507.5	7.0	0.113	0.83	0.281832	0.73	13.1	46			
1770.11.25	0.390	0.015346	12.3	0.46	0.25	3.22	7.3	9.9	9001	0.03	2.8851011	9.7	527.6	5.0	0.056	0.86	0.251704	0.41	13.1	39			
1745.01.75	0.390	0.015670	12.9	0.53	0.28	3.50	7.6	10.88961	0.09	2.6253068	9.5	578.7	6.0	0.056	0.95	0.281799	0.53	14.2	42				
1713.92.25	0.390	0.015515	12.8	0.47	0.31	3.04	6.7	10.67922	0.04	2.7045537	8.9	522.7	7.0	0.056	0.91	0.271903	0.54	13.1	67				

Appendix 1: Framingham Bay (Site 1) metal concentrations in the sediment core from the Great Salt Lake. These concentrations are concentrations per gram of dry sediment. To calculate the actual values measured in the dried sediment+salt mixture, multiply

Site 1	210Pb (estim)	Corr Mid: (fract) Dept of dry	Sedim	Ag	Al	As	Be	B	Cd	Co	Cr	Cu	Fe	Hg	Mo	Na	Ni	P	Pb	Sb	Se	Sn	Sr	Tl	V	Zn
Salt-Corrected Concentrations (ppm)																										
2004.00.25	0.912	6.955	774	19.4	0.63	2.98	5.67	37.4	155.19751	0.90	1.19	6358	13.4	2897	134.80	0.44	2.52	2.93	1358	0.44	22.4	28.2	0.42	21.2	24	
2002.40.75	0.931	0.652	238	18.0	0.57	2.55	5.24	33.2	1335.29059	0.85	1.21	4952	12.0	2273	124.90	0.32	2.20	2.59	1314	0.42	21.2	24	0.43	23.0	25	
2000.81.50	0.952	2.415	463	18.7	0.57	2.82	5.57	35.5	162.59111	0.86	0.98	4387	12.8	2154	126.90	0.42	2.27	2.59	1309	0.43	23.0	25	0.43	23.0	25	
1993.01.75	0.95																									
1995.22.25	0.950	8.154	446	18.6	0.57	2.49	5.18	32.4	138.09090	0.85	1.39	4540	11.9	2088	124.70	0.32	2.17	2.54	1350	0.42	21.9	24	0.42	21.9	24	
1992.32.75	0.952	3.655	508	20.9	0.57	2.73	5.50	35.4	136.09377	0.87	2.84	4198	12.6	2098	113.70	0.42	2.33	2.51	1302	0.46	22.8	25	0.46	22.8	25	
1983.73.25	0.962	1.155	11	22.7	0.58	2.61	5.49	34.9	140.89470	0.84	2.95	3795	12.7	1933	110.30	0.31	2.22	2.45	1337	0.46	22.9	25	0.46	22.9	25	
1985.13.75	0.962	2.284	990	21.2	0.52	2.56	4.77	31.5	144.38933	0.83	2.27	3308	11.2	1701	121.90	0.62	2.30	2.53	1402	0.44	21.6	24	0.44	21.6	24	
1981.64.25	0.972	1.951	106	21.9	0.55	2.61	4.94	33.1	153.99031	0.82	2.65	3582	11.7	1663	123.10	0.31	2.34	2.57	1548	0.42	22.1	23	0.42	22.1	23	
1973.04.75	0.972	3.224	932	19.7	0.55	2.41	4.57	28.7	145.18603	0.81	14.57	3686	10.6	1504	121.30	0.31	2.04	2.47	1480	0.41	20.7	23	0.41	20.7	23	
1974.25.25	0.972	2.349	23	21.1	0.54	2.52	4.79	31.0	139.78700	0.86	3.61	3880	11.4	1565	121.50	0.31	2.27	2.72	1427	0.42	21.7	23	0.42	21.7	23	
1970.45.75	0.982	2.414	891	21.2	0.53	2.72	5.14	36.8	143.18867	0.89	2.32	3636	12.2	1418	118.80	0.31	1.99	3.27	1391	0.41	24.1	23	0.41	24.1	23	
1963.76.25	0.981	5.252	522	21.7	0.58	2.86	5.28	39.2	145.89633	0.84	2.41	4008	12.8	1468	118.90	0.31	2.00	3.12	1371	0.42	24.4	25	0.42	24.4	25	
1962.96.75	0.981	5.059	16	21.9	0.67	3.58	6.03	51.6	152.31066	1.09	4.05	3787	15.1	1291	145.10	0.41	2.19	3.79	1386	0.48	26.7	29	0.48	26.7	29	
1961.67.25	0.981	0.455	244	23.8	0.55	2.96	4.95	30.1	148.79441	1.01	6.96	3528	12.0	991	151.60	0.51	1.68	3.38	1419	0.66	19.7	29	0.66	19.7	29	
1960.37.75	0.981	1.684	886	27.0	0.46	3.03	4.85	14.9	193.78840	0.81	4.69	3888	10.0	843	191.40	0.61	1.89	3.01	1241	0.71	14.1	35	0.71	14.1	35	
1953.98.25	0.990	2.151	109	19.5	0.47	1.40	4.48	9.5	134.79054	0.51	4.27	3888	9.5	807	138.00	0.41	1.50	0.98	1297	0.30	12.0	26	0.30	12.0	26	
1957.68.75	0.990	3.854	467	21.0	0.52	0.98	4.69	9.8	121.59567	0.84	3.62	4430	10.2	742	112.50	0.40	1.65	0.48	1189	0.21	11.5	21	0.21	11.5	21	
1953.09.25	0.992	3.224	986	22.0	0.46	0.54	4.06	8.1	76.98776	0.27	2.65	4467	8.9	719	71.10	0.20	1.43	0.24	1306	0.14	11.1	14	0.14	11.1	14	
1954.59.75	0.980	0.084	433	22.2	0.42	0.17	4.59	7.3	15.97841	0.22	2.54	4593	8.7	631	22.80	0.30	1.55	0.11	1381	0.15	12.0	54	0.15	12.0	54	
1952.90.25	0.980	0.158	39	33.9	0.50	0.27	4.99	9.0	12.19038	0.11	5.43	4968	10.3	705	13.00	0.31	1.47	0.12	1050	0.26	13.8	64	0.26	13.8	64	
1951.40.75	0.980	0.174	62	56.4	0.63	0.31	4.78	8.8	10.51162	0.06	8.23	7190	11.5	769	8.80	0.31	1.50	0.18	907	0.24	14.3	67	0.24	14.3	67	
1943.91.25	0.980	0.165	70	51.8	0.49	0.35	4.15	8.8	12.11003	0.05	5.77	6334	10.0	713	11.60	0.20	1.03	0.22	955	0.22	13.2	64	0.22	13.2	64	
1943.91.75	0.980	0.166	96	53.9	0.59	0.41	4.21	8.8	12.91032	0.05	4.27	6813	10.2	774	14.30	0.31	0.79	0.29	925	0.30	13.1	67	0.30	13.1	67	
1944.02.25	0.980	0.163	93	50.0	0.58	0.32	4.28	9.0	12.71004	0.05	2.52	7859	10.3	713	12.70	0.20	0.76	0.28	902	0.31	12.9	64	0.31	12.9	64	
1933.53.25	0.980	0.163	80	32.5	0.66	0.20	4.18	9.1	9.10277	0.02	0.74	9635	9.9	705	6.20	0.20	0.91	0.19	1074	0.18	12.7	50	0.18	12.7	50	
1932.34.25	0.980	0.165	10	21.6	0.60	0.18	4.16	9.1	9.71049	0.01	0.42	9797	9.8	658	5.70	0.10	0.80	0.21	1081	0.17	12.7	50	0.17	12.7	50	
1931.45.25	0.980	0.161	07	19.4	0.57	0.18	4.17	9.3	9.89840	0.01	0.41	10169	9.8	637	5.50	0.10	0.77	0.22	1043	0.17	12.8	49	0.17	12.8	49	
1930.96.25	0.980	0.165	20	18.5	0.59	0.18	4.42	9.5	9.91048	0.01	0.34	10852	10.2	681	5.80	0.05	0.86	0.14	984	0.17	13.3	52	0.17	13.3	52	
1922.97.25	0.980	0.169	06	18.1	0.58	0.19	4.60	9.8	9.81120	0.01	0.46	11273	10.1	739	5.50	0.10	0.77	0.27	1000	0.18	12.9	54	0.18	12.9	54	
1913.38.25	0.980	0.171	55	15.5	0.57	0.19	4.55	9.8	10.71169	0.01	0.39	10661	10.1	745	6.00	0.10	0.76	0.18	888	0.18	12.2	53	0.18	12.2	53	
1911.69.25	0.990	0.094	547	13.0	0.58	0.18	4.46	9.2	9.859450	0.01	0.44	9721	10.0	671	4.80	0.02	0.63	0.10	892	0.17	13.8	48	0.17	13.8	48	
1907.90.25	0.990	0.141	12	10.8	0.36	0.11	3.69	6.8	6.77453	0.01	0.80	10034	8.0	514	4.00	0.10	0.63	0.07	1537	0.09	11.5	35	0.09	11.5	35	
1904.21.25	0.990	0.094	937	25.1	0.49	0.21	4.23	8.0	8.18742	0.02	3.78	9090	8.9	622	5.90	0.20	0.84	0.12	948	0.24	12.0	44	0.24	12.0	44	
1897.32.25	0.990	0.158	54	41.3	0.51	0.19	4.43	9.2	8.710193	0.01	2.24	10465	9.3	697	5.50	0.20	0.85	0.09	929	0.16	12.0	47	0.16	12.0	47	
1890.33.25	0.990	0.159	50	22.3	0.63	0.19	4.57	9.7	8.791775	0.01	0.79	11639	10.0	657	5.40	0.20	0.60	0.20	853	0.17	12.4	48	0.17	12.4	48	
1883.44.25	0.990	0.159	70	16.7	0.55	0.15	4.45	9.1	7.19800	0.01	0.33	11332	9.3	662	3.90	0.10	0.73	0.09	966	0.12	11.3	44	0.12	11.3	44	
1873.45.25	0.990	0.063	356	14.3	0.33	0.09	3.49	5.8	4.86299	0.01	1.37	8838	5.8	505	4.30	0.10	0.75	0.09	2064	0.08	10.9	31	0.08	10.9	31	
1871.06.25	0.990	0.154	21	15.5	0.48	0.16	4.08	8.2	7.48847	0.01	0.77	11630	8.8	596	4.20	0.10	0.59	0.14	1010	0.38	20.8	60	0.38	20.8	60	
1865.27.25	0.990	0.024	858	18.7	0.45	0.32	5.83	8.3	14.48291	0.02	1.30	12148	8.5	605	9.10	0.20	0.84	0.13	1011	0.33	12.4	48	0.33	12.4	48	
1860.38.25	0.990	0.157	16	50.4	0.53	0.28	4.47	9.8	20.310404	0.02	3.70	11063	9.7	714	11.90	0.30	1.16	0.10	510	0.33	12.4	48	0.33	12.4	48	
1854.99.25	0.990	0.168	29	44.3	0.60	0.33	4.84	11.0	24.912798	0.04	3.02	13269	10.4	632	13.80	0.51	0.88	0.26	834	0.28	14.4	55	0.28	14.4	55	
1843.50.25	0.990	0.055	785	27.7	0.54	0.23	4.27	9.8	15.810502	0.01	1.72	11337	9.5	571	8.80	0.30	0.75	0.13	1052	0.21	13.4	51	0.21	13.4	51	
1844.81.25	0.990	0.161	81	23.6	0.51	0.24	4.68	9.9	12.010779	0.01	2.54	13437	10.2	632	8.80	0.20	0.88	0.17	831	0.27	14.4	58	0.27	14.4	58	
1833.82.25	0.990	0.162	80	34.4	0.59	0.21	4.30	9.4	11.111208	0.02	1.61	14426	9.8	616	7.50	0.30	0.77	0.14	984	0.21	13.7	53	0.21	13.7	53	

Appendix 2. Comparison of the chronologies of metal contaminants (indicator of fluvial transport) at Gilbert Bay Site 3 (A), G (B), and Farmington Bay Site 1 (C). -The plot shows the ratio of metal at a given depth relative to the concentration (pre